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OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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ERRORS IN LONGITUDE, AZIMUTH AND LATITUDE DETERMINATIONS—III.

BY F. A. MCDIARMID

LATITUDE

THERE are three kinds of latitude, geographical, geocentric and astronomical, which may be defined as follows :—

The geographical latitude of a point on the earth's surface is the angle made with the plane of the equator by a normal to the surface at that point.

The geocentric latitude is the angle formed with the plane of the equator by a line joining the point with the earth's centre.

The astronomical latitude is the angle formed with the plane of the equator by a plumb-line at the given point.

If the earth were a true ellipsoid and perfectly homogeneous, the geographical and astronomical latitudes would be the same. In practice, however, the plumb-line is found frequently to deviate from the normal by very appreciable amounts. This deviation is always small, but in mountainous countries, as the Alps and the Caucusus, deviations have been observed as large as 29″. Often in carrying latitudes through the triangles of an

accurate triangulation survey, differences arise which are due to the "pull" of the mountains on the plumb-line. At Covey Hill, in the Province of Quebec, latitude carried from the St. Lawrence River by a series of triangles differed by more than 6″ from the observed latitude at Covey Hill. Similar differences have also been observed in our western country, particularly in the mountains of British Columbia. In this paper astronomical latitude alone will be discussed, and we shall consider for the present that it coincides with geographical latitude.

A reference to Figure 1 will show the difference between geographical and geocentric latitudes. Let the figure represent a section cut from the earth's surface by a plane passing through the axis. This section will be an ellipse. Let K' be any point on the surface, P and P' be the north and south poles respectively. Then $H\,H'$ represents the horizon of the point K'.

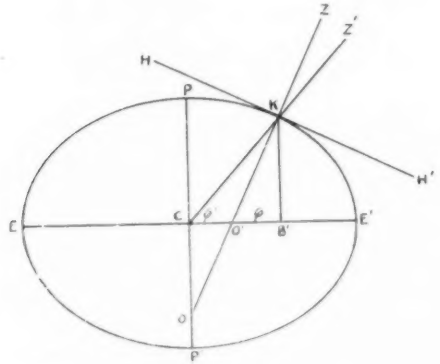

FIGURE 1

ILLUSTRATING THE DIFFERENT KINDS OF LATITUDE

Let $\rho = C\,K' =$ radius of the earth for latitude $K'\,O'\,E'$,
$\phi = K'\,O'\,E' =$ geographical latitude of the point K',
$\phi' =$ geocentric latitude of the point K',
$A =$ semi-major axis of the ellipse $= C\,E'$,
$B =$ semi-minor axis of the ellipse $= C\,P$.

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The angle $C K O = \phi - \phi'$ is called the reduction of the latitude. For the determination of parallax with precision we require $\phi - \phi'$ and ρ, but for the purpose of this article they are not necessary and will not be discussed further.

Consider a spherical triangle $Z P S$ on the celestial sphere, where Z is the zenith, P the pole and S the star.

If ϕ = latitude of the observer, then $Z P = 90° - \phi$,
and if δ = declination of the star, then $P S = 90° - \delta$,
and if t = hour angle of the star, then angle $P Z S = t$,
and $Z S$ = zenith distance of the star = z;
then $\cos z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t$ . . . . . (1)

This is the formula that is used in reducing latitudes.

Latitude is determined in many ways, but only a few of the more important will be discussed here.

(1)—LATITUDE BY THE ZENITH DISTANCE OF A STAR OBSERVED IN THE MERIDIAN

Considering the above equation (1) when the star is on the meridian, $t = 0$ and $\cos t = 1$.

Then $\cos z = \sin \delta \sin \phi + \cos \delta \cos (\phi - \delta)$,
whence $\pm z = \phi - \delta$; or $\phi = \pm z + \delta$

The + sign is used for stars south of the zenith and − sign for stars north of the zenith. The same applies for stars below the pole for which $\phi = (180° - \delta) - z$.

If the star is observed at both upper and lower culminations, we have for lower culmination $\phi = (180° - \delta) - z$,
and for upper culmination $\phi = \delta - z'$.

Adding, $2 \phi = 180° - (z + z')$
or $\phi = 90° - (z + z')/2$.

The latitude thus obtained does not require a knowledge of the declination of the star; it is, therefore, adapted to the determination of the latitude of a fixed observatory, where it is desired to have an absolutely independent result.

(2)—LATITUDE BY OBSERVATION OF THE ALTITUDE OF A STAR, THE TIME BEING KNOWN

If θ is the known sidereal time, and α the right ascension and δ the declination of the star are taken from the ephemeris, then $t = \theta - \alpha$. Also $z = 90° - h$, where h = altitude of the star.

Then equation (1) becomes

$$\sin h = \sin \delta \sin \phi + \cos \delta \cos \phi \cos t,$$

where ϕ is the only unknown quantity.

The equation in this form is not suited to computation, but as the method of transforming it is of easy access in standard works (Chauvenet, *Spherical and Practical Astronomy*, Vol. I., p. 229; Campbell, *Practical Astronomy*, p. 110) it is not given here.

(3)—LATITUDE BY CIRCUM-MERIDIAN ALTITUDES

When the latitude is determined by the observation of a star on the meridian, the accuracy is greater than in any other method. As, however, only one observation can be taken of a star in the meridian, and as often the time of transit is not known with sufficient accuracy at the time of observation to determine the exact instant of meridian passage, altitudes may be observed near the meridian, and reduced to the meridian by a simple computation. In this way several observations may be taken on either side of the meridian. The series need not be symmetrical with respect to the meridian, as the method is equally applicable to one or more altitudes on either side of the meridian.

This method is also discussed in the standard works just mentioned, (Chauvenet, p. 238; Campbell, p. 112) and the formulæ need not be given here.

This method has been used in some of the Canadian work and the results obtained speak well for it. Its main advantage is that the stars used are all standard stars, and consequently the errors of declination are very small. The disadvantages arise from division errors of the vertical circle, from errors in refraction and from errors in estimating the instant of observation.

Below (Table I.) will be found the results of observations taken at Cobourg and Beeton by Mr. F. W. O. Werry in the season of 1904.

TABLE I.

COBOURG, AUGUST 4, 5, 6, 1904

Star No.	South Reading	Star No.	North Reading	Latitude
	° ′ ″		° ′ ″	° ′ ″
478	43 58 35·27	235	43 57 08·46	43 57 51·86
241	32·40	236	09·76	51·08
246	32·33	485	09·13	50·73
254	33·02	487	10·41	51·71
270	33·13	265	10·82	51·98
275	31·81	271	09·57	50·69
290	33·91	282	09·29	51·60
237	36·44	235	06·15	51·30
246	32·92	482	09·80	51·36
258	32·75	256	08·83	50·87
270	33·99	265	10·34	52·16
279	33·68	271	08·26	50·97
286	33·30	502	09·19	51·25
231	33·35	235	08·28	50·82
275	34·50	483	08·90	51·70
279	35·33	248	08·42	51·87
255	33·55	271	08·81	51·18
286	37·14	502	07·02	52·08

Latitude of Cobourg 43° 57′ 51″·40 ± ″·07

BEETON, SEPTEMBER, 1904

Star No.	North Reading	Star No.	South Reading	Latitude
	° ′ ″		° ′ ″	° ′ ″
248	44 04 47·57	254	44 04 48·84	44 04 48·20
487	47·79	266	47·94	47·86
259	47·83	270	46·18	47·01
490	47·32	277	47·00	47·16
273	48·76	286	46·26	47·51
502	49·51	290	43·88	46·73
508	48·85	295	46·31	47·58
510	49·25	512	44·98	47·12
308	50·48	309	45·57	48·02
490	42·86	266	52·07	47·46
271	43·60	270	51·68	47·64
502	45·05	274	50·58	48·31
508	45·16	283	50·60	47·88
497	39·58	270	54·40	46·99
502	40·33	277	54·84	47·58
219	41·80	286	51·71	46·76

Latitude of Beeton 44° 04′ 47″·49 ± ″·10

On account of the collimation of the instrument, a north star of a certain zenith distance is paired with a south star of about the same zenith distance. The mean of the two results will be nearly free from errors due to collimation; it is always well to reduce the collimation as much as possible.

(4)—TALCOTT'S ZENITH DISTANCE METHOD

In the first method described above a measurement of the meridional zenith distance of a known star furnishes a determination of the latitude of a station. In the Horrebow-Talcott or Talcott method, as it is usually called, there is substituted for the measurement of the absolute zenith distance of a star, the measurement of the small difference of meridional zenith distance of two stars culminating at about the same time, and on opposite sides of the zenith. The effect of this substitution is the attainment of a much greater degree of precision, arising from the differential measurement, in general over the corresponding absolute measurement; from the elimination of the use of a graduated circle; and from the fact that the computed result is effected, not by the error in estimating the absolute value of the astronomical refraction, but simply by the error in estimating the very small difference of refraction of two stars at nearly the same altitude.

The Talcott method has been used extensively by the United States Coast and Geodetic Survey, and nearly all our Canadian latitudes have been observed by this method. The writer has during the past few years observed about sixty-five stations, making at each station about seventy-five observations. It is the intention to treat of this method somewhat fully; a description of the instrument employed, adjustment of the instrument, programme of stars for observation, number of pairs observed, number of times each pair observed, and the chief sources of error will be discussed. The results from a number of stations, namely, Stony Plains, Prince Rupert, Atlin and Field, will be given and an attempt will be made to outline some guide in order to secure the most accurate latitude determination.

(*a*) INSTRUMENT AND ADJUSTMENT

The instrument used for latitude observations by this method is the zenith telescope. The Cooke transits of the Dominion Observatory are readily converted into zenith telescopes by fixing to the setting circle a good level, and by turning the eye-piece through 90° in order to have the micrometer wire move in zenith distance instead of longitudinally across the meridian.

The telescope has a focal length of thirty-six inches, a clear aperture of two and one-half inches, and a magnifying power of about forty. The value of one division of the striding level is 1″·50, and the value of one division of the latitude level is 1″·136. When the eye-piece of the instrument is turned through a right angle, and is ready for zenith distance readings we have two vertical wires and one horizontal wire. Care must be taken to see that the two vertical wires are at equal distances on either side of the meridian. This condition is secured by adjusting the frame which carries the wires. Also the micrometer wire must be exactly horizontal. This adjustment can be made by following several stars across the field and adjusting for any deflection from the horizontal. The instrument should be levelled by means of the striding level; but a small difference in level between the ends of the axis has an almost inappreciable effect on a latitude observation. Every care must be taken in handling the micrometer screw, as any longitudinal force applied to it produces a flexure of the telescope which tends to enter into the result directly as an error. The lost motion of the micrometer head should always be in one direction, (preferably that in which the screw acts positively against its opposing spring), to insure that any lost motion is always taken up in one direction. The level bubble should always be read promptly, so as to give as little time as possible to change after the bisection. The desired reading is that at which it stood at the instant of bisection. Care must also be taken to avoid any heating of the level by putting the reading lamp, warm breath or face any nearer to it than necessary. During the time of observation of the pair the tangent screw of the setting circle carrying the latitude level

must not be touched, since the angle between the level and the telescope must be kept constant. It is desirable to keep the correction for level small, in order to eliminate as far as possible any error arising from an inaccurate assumed value of one division of the level.

The value of one division of the level may be determined by an instrument called a level trier. The level should be re-determined frequently, as even a good level will deteriorate through time.

The value of one revolution of the micrometer screw may be determined from transits of a polar star across the meridian. This should also be determined frequently as some screws will vary from time to time owing to wear of parts of the screw. The value of one revolution of the micrometer screw may also be determined from the latitude observations, but the value so obtained will depend upon the declination of the stars, and so will likely be slightly in error.

(*b*) PROGRAMME

In preparing a suitable list of stars for observation by Talcott's method, the approximate latitude is required.

If ϕ = latitude of station of observation,
δ = declination of the south star,
δ' = declination of the north star.
and z and z' the zenith distances of the stars.

Then $\phi = \delta + z$,
and $\phi = \delta' - z'$;
Adding $2\,\phi = \delta + \delta' + (z - z')$.

It is necessary to choose δ and δ', the declinations of the south and north stars respectively so that $\delta + \delta' = 2\,\phi$ approximately.

The quantity $(z - z')$ must be read on the micrometer and level. As pointed out above, the level correction should be small, preferably within one division of the level. The micrometer correction should also be as small as possible, not exceeding

twenty turns of the micrometer screw. It is also well in selecting the pairs to have the positive micrometer differences equal to the negative differences. The two stars of a pair should differ in right ascension by at least three minutes, and by not more than fifteen minutes. Also the stars of two pairs should be separated by at least three or four minutes. This will give sufficient time for the level bubble to settle, and for the setting and reading of the micrometer.

The stars used by the Canadian observers are selected from Ambronn's *Sternverzeichniss*, and generally about seven pairs an hour can be obtained.

(*c*) COMPUTATIONS

If δ and δ' are the declinations of the stars, z and z' the zenith distances, then as above

$$\phi = (\delta + \delta')\,2 + (z - z')/2.$$

Let M and M' be the micrometer readings and n, s and n', s' be the readings of the ends of the level bubble, if the bubble reads from the end.

Then

$$(z - z')/2 = (M - M')\,R/2 + d\,\{(n + s) - (n' + s')\}/4 + (r - r')/2$$

where R = value of one revolution of micrometer in seconds of arc,

d = value of one division of the level in seconds of arc,

and r and r' are the refraction corrections.

Then we have

$$\phi = (\delta + \delta')/2 + (M - M')\,R/2 + d\,(n + s - n' - s')/4 + (r - r')/2.$$

Again δ and δ' are the apparent declinations of the stars; to deduce the apparent declinations from the mean declinations we can use either of the two formulæ,

$$\delta = \delta_0 + v\,u' + g\cos(G + \alpha_0) + h\cos(H + \alpha_0)\sin\delta_0 + i\cos\delta_0,$$

in which δ_0 and α_0 are the mean declination and right ascension respectively, u' is the proper motion of the star and v is the fraction of the year elapsed; or,

$$\delta = \delta_0 + v\,u' + A\,a' + B\,b' + C\,c' + D\,d'.$$

The former of these is the better adapted for use in the

reductions, as the quantities g, G, h, H and i can all be taken directly from the ephemeris.

Until recently the apparent declinations of the two stars of a pair were reduced separately, but a few years ago Mr. W. M. Tobey, of the Observatory Staff, combined the two reductions into one.

Assume δ and δ to be the apparent declinations of the south and north stars of a pair, and δ_0, δ'_0 the mean declinations and α_0, α'_0 the mean right ascensions of the stars, respectively.

Then for the south star,

$$\delta = \delta_0 + v\,u + g \cos (G + \alpha_0) + h \cos (H + \alpha_0) \sin \delta_0 + i \cos \delta_0.$$

For the north star,

$$\delta' = \delta'_0 + v'\,u' + g \cos (G + \alpha'_0) + h \cos (H + \alpha'_0) \sin \delta'_0 + i \cos \delta'_0.$$

Adding,

$$\delta + \delta' = \delta_0 + \delta'_0 + v\,u + v'\,u' + g \left\{ \cos (G + \alpha_0) + \cos (G + \alpha'_0) \right\}$$
$$+ h \left\{ \cos (H + \alpha_0) \sin \delta_0 + h \cos (H + \alpha'_0) \sin \delta'_0 \right\} + i \cos \delta_0 + \cos \delta'_0).$$

Now $\cos (G + \alpha_0) + \cos (G + \alpha'_0) = 2 \cos \left\{ G + \tfrac{1}{2} (\alpha_0 + \alpha'_0) \right\}$ $\cos (\alpha_0 - \alpha'_0)$.

Here $(\alpha_0 - \alpha'_0)$ is small and $\cos (\alpha_0 - \alpha'_0) = 1$ approximately.

Then $\cos (G + \alpha_0) + \cos (G + \alpha'_0) = 2 \cos \left\{ G + \tfrac{1}{2} (\alpha_0 + \alpha'_0) \right\}$ nearly.

Again,

$$\cos (H + \alpha_0) \sin \delta_0 + \cos (H + \alpha'_0) \sin \delta'_0$$
$$= \cos (H + \alpha_0) \sin (\lambda - x) + \cos (H + \alpha'_0) \sin (\lambda + x),$$

which, on expansion and reduction,

$$= 2 \sin \phi \cos x \cos \tfrac{1}{2} (H + \alpha_0 + \alpha'_0) \text{ nearly.}$$

In the above λ is assumed equal to $\tfrac{1}{2} (\delta_0 + \delta'_0) = \phi$ nearly; and x is approximately the zenith distances of the stars. Also put $\cos \tfrac{1}{2} (\alpha_0 - \alpha'_0) = 1$ and $\sin \tfrac{1}{2} (\alpha_0 - \alpha'_0) = 0$.

Again,

$$i \cos \delta_0 + i \cos \delta'_0 = 2\,i \cos \tfrac{1}{2} (\delta'_0 + \delta_0) \cos \tfrac{1}{2} (\delta'_0 - \delta_0)$$
$$= 2\,i \cos \phi \cos x$$

$$\text{or } \delta + \delta' = \delta_0 + \delta'_0 + v\,u + v'\,u' + g \cos \left\{ G + \tfrac{1}{2} (\alpha_0 + \alpha'_0) \right\}$$
$$+ h \cos \left\{ H + \tfrac{1}{2} (\alpha_0 + \alpha'_0) \right\} \sin \phi \cos x + i \cos \phi \sin x$$
approximately. (2)

The error in assuming that formula (2) is correct is less than 0″·10 in the extreme limits of the stars used in the observation of latitude. The errors in the several pairs are both positive and negative, and nearly disappear entirely in the mean of thirty or more pairs at a station. In any event any errors introduced by these assumptions are masked many times by other errors which can not be made to disappear.

The formula as deduced is especially suitable for use with an arithmometer as the terms g, h, i, sin ϕ and cos ϕ are constant for every observation on a night, and the terms sin ϕ and cos ϕ are constant for all the observations at a station. The use of this formula has reduced the labor of computation by more than half. If it were desirable to include a correction owing to the above approximation, tables can be prepared and the small corrections applied to the final result.

The difference of refraction for any pair of stars is so small that the variation in the state of the atmosphere may be neglected. The refraction is nearly proportional to the tangent of the zenith distance, and, therefore, the difference of refraction for the two stars will be given by

$$r - r' = 57''{\cdot}7 \sin (z - z') \sec^2 z,$$

and since the differences of zenith distances is measured by the micrometer, the following table of correction to the latitude for differential refraction has been prepared for the argument one-half the difference of zenith distance.

If the stars are observed off the meridian, a small correction is applied as is done in the case of circum-meridian observations, but in the Canadian work care is taken to make the bisection of the star at the exact instant of its crossing the line of collimation of the telescope.

TABLE II.

Correction to latitude for differential refraction = $\frac{1}{2}(r - r')$.

ZENITH DISTANCE

Half of diff. of zenith distance	0°	10°	20°	25°	30°	35°	40°	45°
′	″	″	″	″	″	″	″	″
0	·00	·00	·00	·00	·00	·00	·00	·00
0·5	·01	·01	·01	·01	·01	·01	·01	·02
1	·02	·02	·02	·02	·02	·02	·03	·03
1·5	·03	·03	·03	·03	·03	·03	·04	·05
2	·03	·03	·04	·04	·04	·05	·06	·07
2·5	·04	·04	·05	·05	·05	·06	·07	·08
3	·05	·05	·06	·06	·07	·08	·09	·10
3·5	·06	·06	·07	·07	·08	·09	·10	·12
4	·07	·07	·08	·08	·09	·10	·11	·13
4·5	·08	·08	·09	·09	·10	·11	·13	·15
5	·08	·09	·10	·10	·11	·13	·14	·17
5·5	·09	·10	·10	·11	·12	·14	·16	·18
6	·10	·10	·11	·12	·13	·15	·17	·20
6·5	·11	·11	·12	·13	·14	·16	·19	·22
7	·12	·12	·13	·14	·15	·18	·20	·24
7·5	·13	·13	·14	·15	·16	·19	·21	·25
8	·13	·14	·15	·16	·18	·21	·23	·27
8·5	·14	·15	·16	·17	·19	·22	·24	·29
9	·15	·16	·17	·18	·20	·23	·26	·30
9·5	·16	·17	·18	·20	·21	·24	·27	·32
10	·17	·18	·19	·21	·23	·26	·29	·34
10·5	·18	·19	·20	·22	·24	·27	·30	·35
11	·18	·19	·21	·23	·25	·28	·31	·37
11·5	·19	·20	·22	·24	·26	·30	·33	·39
12	·20	·21	·23	·25	·27	·31	·34	·40
12·5	·21	·21	·24	·26	·28	·32	·36	·42

The sign of the correction is the same as that of the micrometer difference.

(*d*)—COMBINATION OF RESULTS

Separate values of the latitude are computed from each observation on each pair, and it remains to combine them to obtain the most probable value. For ordinary geographical purposes the arithmetic mean of all the observations will be sufficient. However, to obtain the best value we shall consider how to group the observations and what weight to give the different pairs.

Let p = total number of pairs observed, and the number of

observations upon the first pair be n_1, upon the second pair n_2, and so on ; and let the total number of observations taken at a station be n which is equal to $n_1 + n_2 + n_3 + n_4 +$ etc.

Let Δ be a residual obtained by subtracting the result of a single observation on a pair from the mean of all the observations on that pair.

Let e be the probable error of a single observation of the latitude, excluding the error arising from defective adopted declinations.

The various values of Δ depend upon and are a measure of the probable error, but are independent of the errors of declination.

Accordingly

$$e^2 = \frac{\cdot 455 \, \Sigma \, \Delta^2}{\text{No. obs.} - \text{No. unknown}} = \frac{\cdot 455 \, \Sigma \, \Delta^2}{n - p}$$

Let ϕ_1 be the mean latitude obtained from the first pair, ϕ_2 from the second pair, etc.

Let v be the residual obtained by subtracting ϕ_1, ϕ_2, ϕ_3, ϕ_4, etc., in turn from the indiscriminate mean value for the station of ϕ_1, ϕ_2, ϕ_3, ϕ_4, etc. There will be p such residuals, and they are a measure of the probable error of the mean result from a pair, which we shall call e_p, arising from both errors of observation and declination.

$$e_p = \frac{\cdot 455 \, \Sigma \, v^2}{p - 1}.$$

Let e_{p1}, e_{p2}, e_{p3}, etc., be the probable errors respectively of ϕ_1, ϕ_2, ϕ_3, etc., and let E be the probable error of the mean of the two declinations.

$$\text{Then } e^2_{p1} = E^2 + e^2 / n_1 \, ; \; e^2_{p2} = E^2 + e^2 / n_2 \, ; \text{ etc.}$$

These different values of e^2_{p1}, e^2_{p2}, e^2_{p3}, etc., differ from each other because of the various values of n_1, n_2, n_3, etc., even though E^2 and e^2 are constant. and the value derived for e^2_p is their mean value. Adding these various equations, p in number, member by member, there is obtained

$$\epsilon^2_p = E^2 + \frac{e^2}{p}\left(\frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} + \text{etc.}\right),$$
$$= E^2 + \epsilon^2;$$

or $E^2 = \epsilon^2_p - \epsilon^2$, where $\epsilon^2 = \frac{e^2}{p}\left(\frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} + \text{etc.}\right)$.

Having determined the values of E^2 and e^2, the proper relative weights, w_1, w_2, w_3, etc., inversely proportional to the squares of the probable errors, may now be assigned to ϕ_1, ϕ_2, ϕ_3, etc.

$$w_1 = 1/\epsilon^2_{p1}, \quad w_2 = 1/\epsilon^2_{p2}, \text{ etc.}$$
$$\text{or } w_1 = 1\Big/\left(E^2 + \frac{e^2}{n_1}\right), \quad w_2 = 1\Big/\left(E^2 + \frac{e^2}{n_2}\right), \text{ etc.}$$

Occasionally two or more south stars may be observed with one north star, or *vice-versa*. The results will not be independent, since they involve in common the error of observation and the error of declination of the common star. The weight to be assigned to each component pair in a doublet is two-thirds of that given above, and of each component pair in a triplet is one-half. Again, if a given star on one side of the zenith is observed on a certain night, and with another star on other nights, the two results are independent in so far as observation is concerned, but involve a common adopted declination for one of the stars of each pair. The proper weights to be assigned depends upon the relative value of E and e, but is very nearly the same as for independent pairs.

The most probable value ϕ_0 for the latitude of the station is the weighted mean of the mean results from the various pairs, or

$$\phi_0 = \frac{w_1\phi_1 + w_2\phi_2 + w_3\phi_3 + \text{etc.}}{w_1 + w_2 + w_3 + \text{etc.}}.$$

The probable error of ϕ_0 is $= \sqrt{\frac{\cdot 455\ \Sigma\, w\, \Delta\, \phi^2}{(p-1)\ \Sigma\, w}}$,

in which $\Delta\phi$ is the residual obtained by subtracting ϕ_1, ϕ_2, ϕ_3, etc., in turn from ϕ_0.

In Table III. some information is given regarding the deter-

mination of the latitude of Stony Plains, Prince Rupert, Atlin and Field. These give a fair indication of the latitude determinations by Canadian observers.

TABLE III.

Station	Final Latitude				e^2_p	e^2	E^2	e
	°	′	″					
Stony Plains	53	31	47·37	± ·09	·1855	·0758	·1097	± ·09
Prince Rupert	54	18	32·03	± ·10	·3290	·1140	·2150	± ·10
Atlin	59	34	20·094	± ·12	·4090	·0600	·3490	± ·12
Field	51	23	35·94	± ·11	·3910	·1080	·2830	± ·11

An examination of the different observations at these stations shows that the errors of the adopted declinations are larger than the errors of observation. The observations at Stony Plains give the greatest difference between two observations on the same pair 2″·53, and the greatest difference between any two observations 3″·75. The Prince Rupert observations give a difference of 2″·85 between two observations on the same pair, and a difference of 4″·31 between any two observations. The Atlin results show a range of 2″·32 between two observations on the same pair, and a range of 4″·76 between any two observations; and the Field observations give the greatest difference between two observations on the same pair 2″·44, and the greatest difference between any two observations 4″·17. It appears from this comparison that the errors of observation are of about the same magnitude at all these stations, and that the errors of declination are larger than the errors of observation.

The errors in the adopted declinations are due more to faulty proper motions, than to errors in the mean places for the epoch of observation. The places of the stars used have been compiled from old catalogues, and the errors of the catalogue combined with errors in the proper motions have produced in the adopted declinations, errors of by no means desirable dimensions. As stated earlier in this paper, the latitude programmes were prepared from the Ambronn *Sternverzeichniss*, but to obtain

the best value for the declinations, a number of star catalogues have been employed. The different star catalogues rank in order of precedence as folows :—Berliner *Astronomisches Jahrbuch*, *American Ephemeris*, *Nautical Almanac*, and *Connaissance des Temps*, nearly equal ; the places of the Greenwich 10-year catalogue with the proper motions of Lewis Boss are given second place ; the places of the Boss catalogue are given third place ; and the declinations of Ambronn for any stars not found in the preceding lists. But the great need, as the observations clearly show, is a larger number of well defined star places ; work is now being commenced at the Dominion Observatory to furnish the field observers with a list of well defined star places.

The errors of observation nearly disappear in the mean of three or four observations on a pair ; these errors come from inaccurate level reading, from poor setting on the star images, and from errors in estimating or recording the micrometer.

An examination of the observations at the stations of 1909 showed that the combined error of setting on the star images and of level reading was about $\pm$ ″·45. The error of setting on a star image is nearly the same as setting on the azimuth signal described earlier in this paper. The probable error of setting on such a mark is about $\pm$ ″·25. If we assume our errors of setting on the star images to be $\pm$ ″·25, then the probable error of the difference of the two settings will be about

$$\pm \sqrt{(\cdot 25)^2 + (\cdot 25)^2} = \pm \sqrt{\cdot 1300}.$$

The probable error due to level reading will then be

$$\pm \sqrt{(\text{″}\cdot 2025) - (1300)}, \text{ or } \pm \sqrt{(\text{″}\cdot 0725},$$

or the probable error of a single level reading is about $\pm$ ″·20, or the error of the level is nearly the same as the error due to the micrometer.

(*c*)—THE ECONOMICS OF LATITUDE OBSERVATIONS

Two questions here present themselves. What ratio of number of observations to number of pairs will give the maxi-

mum accuracy for a given expenditure of time? What degree of accuracy is it justifiable to strive for?

The answer to the first of these questions depends upon the relative accuracy of the accidental errors of declination and observation.

The weight to be assigned to the mean latitude from a single pair is $1 / (E^2 + e^2/n)$. The following table gives the most economical ratio of number of observations to number of pairs. In this table E has been assumed to be $\pm$ ″·16.

TABLE IV.

NUMBER OF OBSERVATIONS ON THE PAIR

e	1	2	3	4	5	6
± ″·16	20	26	29	31·2	32·6	33·4
± ″·20	15	22	26	28·1	29·8	31·0
± ″·30	9	14	18	20·8	22·9	24·6
± ″·40	5·4	9·5	12·7	15·2	17·4	19·1
± ″·60	2·6	4·9	6·9	8·7	10·2	11·7
± ″·80	1·5	2·9	4·2	5·4	6·5	7·6
± 1″·00	1·0	1·9	2·8	3·6	4·4	5·2

The average of efficiency of the first observation is the weight shown in the first column, and of each succeeding observation is the resulting increment of weight. If $e = \pm$ ″·16, the first observation has a weight of 20, while the second observation is less than one-third as efficient, and the fifth and sixth observations combined are less than one-ninth as efficient as the first. Therefore, little is to be gained by increasing the number of observations on a pair, while the delination error is allowed to remain large.

The figures shown in the above table are based upon assuming the probable error of declination to be ± ″·16. In the stars available for the Canadian work, the average probable error of the declinations is considerably larger.

From the result of the past five years, it would appear that the probable errors of declination and observation are about ± ″·30 and ± ″·35, respectively. The following table will then

represent the most economical ratio of number of observations to number of pairs.

NUMBER OF OBSERVATIONS ON THE PAIR

e	1	2	3	4	5	6
$\pm$ ″·35	4·7	6·6	7·7	8·3	8·9	9·1

The measure of the efficiency of the first observation is 4·7, of the second 1·9, of the third 1·0, etc. There is, therefore, little to be gained by increasing the number of observations on a pair beyond two. To increase the accuracy of the final result it is better to increase the number of pairs, and so decrease the effect of errors of declination. If instead of repeating observations on the same pairs on different nights, a new programme were prepared and a new list of stars observed, the accuracy of the final latitude would be greatly increased. The great need is more fundamental observations for the definition of star places, and it is a need that can only be met after years of hard work with the meridian circle.

The probable error of observation includes the errors of the micrometer and level. In preparing the list of pairs, often two or more stars on one side of the zenith would be paired with a star on the opposite side, thus giving an opportunity of determining the probable error of the micrometer readings; since the difference of altitude of the stars of the pair on the same side of the zenith is constant. The probable error of the level was then found by taking the difference between the probable error of a single determination of latitude and the probable error of the micrometer reading. The probable errors of a single determination, of micrometer settings, and of level readings at a number of stations, are as follows:—

Moricetown	$\pm$ ″0·45	$\pm$ ″0·20	$\pm$ ″0·40
Bamfield	$\pm$ 0·40	$\pm$ 0·26	$\pm$ 0·30
Bella Coola	$\pm$ 0·39	$\pm$ 0·25	$\pm$ 0·30
Murray Hill	$\pm$ 0·38	$\pm$ 0·23	$\pm$ 0·30
Edmonton	$\pm$ 0·33	$\pm$ 0·19	$\pm$ 0·27
Sixth Cabin	$\pm$ 0·33	$\pm$ 0·19	$\pm$ 0·27

These results show that the errors due to level are slightly larger than the errors due to micrometer, which is in fair accord with the conclusion reached earlier in this paper.

(*f*)—VARIATION IN LATITUDE

The axis about which the earth rotates was found by Kustner to be affected by a small motion with respect to the earth. The effect of such a change in the earth's axis is to alter the positions of the terrestrial poles and consequently of the terrestrial equator, and hence the latitude of any point on the earth's surface undergoes changes not due to actual motion in the point, but to changes in the base from which the latitudes are measured. The first systematic investigation of this subject was made in 1891 by Chandler who showed that the observed changes in latitude could apparently be explained by the supposition that the pole of the earth described a circle with a radius of thirty feet in a period of fourteen months. Later investigations by Chandler himself and others, while substantiating the general fact that the pole is in movement, have shown that the character of that movement is not quite so simple as at first supposed. There is reproduced in Figure 2, the diagram given by Professor Albrecht in *Astronomische Nachrichten*, Nr. 4187, as a provisional result of the work of the International Geodetic Association. In this diagram the centre of the figure is the mean position of the north pole in the earth, and the points marked on the curves indicate the actual positions of the pole at the corresponding times. Thus, for example, the curve nearest the centre shows the movement of the pole from 1899·9 to 1901·0, from whence it can be traced forward in its various convolutions up to 1907·0. It will be seen that the positions of the pole are included in a square, each side of which subtends about 0″·50 at the earth's centre. The movements of the pole during the six years are thus comprised within a square of which the sides are not more than 50 feet. The individual positions are no doubt subject to considerable uncertainty.

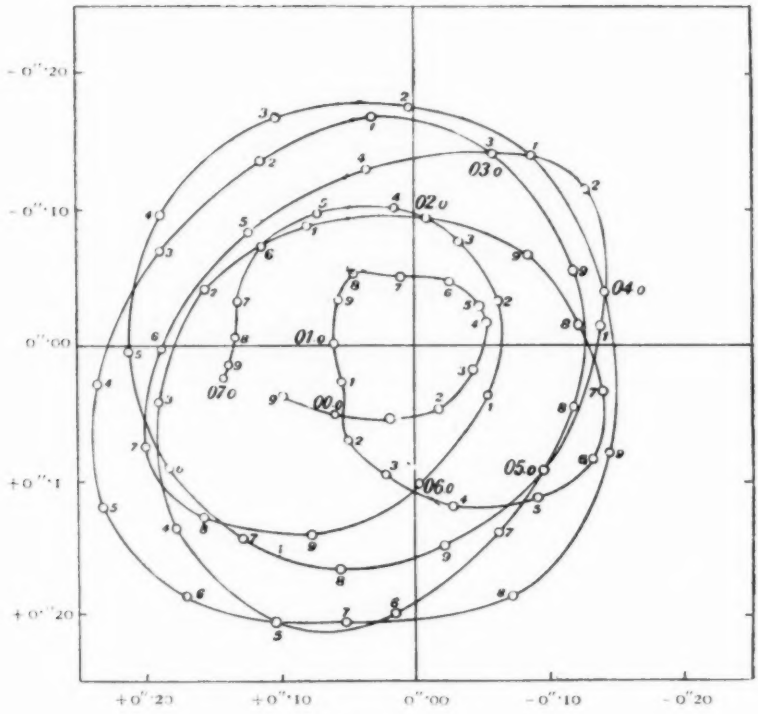


FIGURE 2.

THE MOTION OF THE POLE FROM 1900 TO 1907

Figure 3 shows the variation of latitude at South Bethlehem from 1894, January 19, to 1895, August 19.

In the latter part of 1899 six astronomical stations were established in the northern hemisphere, for the purpose of making systematic observations for the latitude of each station, in order to determine the variations in this quantity. Observations at the six stations have been carried on continuously since they were established without serious interruptions from any cause, and are to be continued into the future for an indefinite time. This work is being prosecuted by the International Geodetic

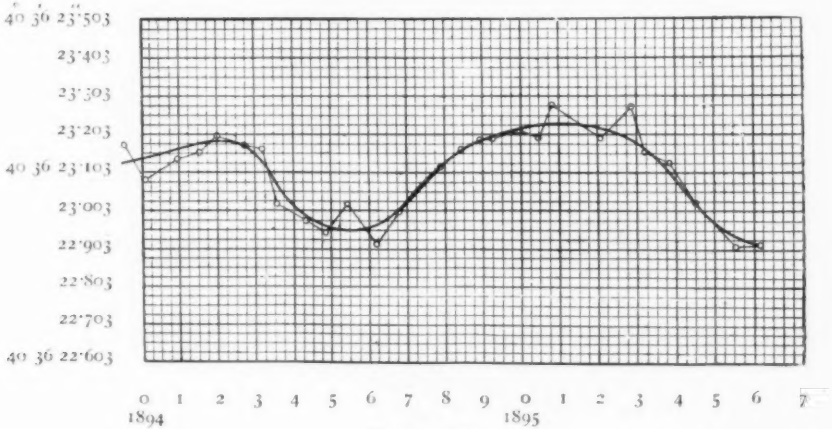


FIGURE 3

DIAGRAM SHOWING VARIATION OF LATITUDE AT SOUTH BETHLEHEM FROM 1894, JANUARY 19, TO 1895, AUGUST 19

Association which has headquarters at Potsdam, Germany. This association was formed for the purpose of conducting geodetic undertakings which are international in character. It is supported by the most prominent nations in the world, including nearly all the governments of Europe, the United States, the Argentine Republic and Japan. The geodetic institutes of the various countries in which the latitude stations are located co-operate with the central station in carrying on this patticular piece of work, the three stations in the United States being under the supervision of the Coast and Geodetic Survey.

In concluding these papers on "Errors in Longitude, Azimuth and Latitude Observations," the writer desires to express his thanks to Dr. W. F. King, Chief Astronomer, for permission to publish them.

DOMINION OBSERVATORY,
OTTAWA, CANADA.

THE ORBIT OF BOSS 3323

By J. B. Cannon

THREE measures of this star ($\alpha = 12^h\ 41^m\ 2$, $\delta = +\ 8^\circ\ 9'$) were published by Adams in the *Publications of the Astronomical Society of the Pacific*, December, 1914, and gave a range of 56·8 km. The spectrum is of *A5p* type. The wave-lengths of the lines measured are given in Table 1. together with the elements to which they are due.

TABLE I.

Wave-Length	Element	Wave-Length	Element
4549·766	Iron	4233·328	Mn.-Fe
4481·400	Magnesium	4215·668	Fe
4352·006	Mg.-Cr.	4198·494	Fe
4340·634	H	4101·890	H
4325·939	Fe	4077·885	Sr
4315·178	Fe-Ti	4063·756	Fe
4289·915	Cr.-Ti	4045·975	Fe
4271·760	Fe	4005·355	Fe
4260·640	Fe	3933·825	Ca
4250·616	Fe		

Thirty-nine plates were taken between February 17 and June 6 of this year. The period, 38·3 days, cannot be considered very closely determined as the interval of observation is short, and furthermore, the Adams observations were only taken in 1913, and their positions, as will be seen in the figure, are such that a change in the period, (either increase or decrease), would improve one of them while making a greater residual for the other.

On twelve plates double lines were measured, and as these occur only at maximum and minimum it would appear that they are real instances of doubling.

Table II. gives the Adams observations, their phases, and residuals from the final curve.

Table III. gives the Ottawa observations of the primary component and Table IIIA. the Ottawa observations of the secondary.

TABLE II.—ADAMS OBSERVATIONS

Date	Julian Day	Phase	Velocity	Residual
1913				
May 25	2,419,913·798	29·743	− 42·8	− 3·0
June 17	936·705	14·350	+ 34·0	+ 4·0
July 16	965·700	5·045	− 10·7	− 5·0

TABLE III.—OTTAWA OBSERVATIONS

Plate	Obs.	Date	Exp.	Julian Day	Phase	Velocity	Wt.	O–C
		1915	m					
6791	C	Feb. 17	70	2,420,546·764	11·609	+ 30·7	2	+ 2·7
6815	Y	Feb. 21	75	550·661	15·506	+ 20·6	2	− 8·4
6821	Y	Feb. 28	70	557·712	22·557	+ 5·6	4	+ 3·8
6824	H	Mar. 1	72	558·840	23·685	− 0·8	6	+ 3·7
6831	C	Mar. 3	95	560·796	25·641	− 16·1	6	+ 0·1
6839	Y	Mar. 4	70	561·759	26·604	− 21·3	7	+ 0·9
6853	Y	Mar. 9	55	566·710	31·555	− 57·3	6	− 10·1
6858	H	Mar. 11	60	568 710	33·555	− 54·1	7	− 2·5
6871	H	Mar. 15	68	572·730	37·575	− 49·0	7	− 4·0
6877	H	Mar. 18	55	575·686	2·231	− 19·2	2	+ 7·1
6885	H	Mar. 22	80	579·676	6·221	+ 7·0	5	+ 4·4
6888	Y	Mar. 23	70	580·656	7·201	+ 4·8	5	+ 4·5
6894	H	Mar. 29	70	586·661	13·206	+ 20·3	4	− 9·7
6898	Y	Mar. 30	60	587·698	14·243	+ 28·7	4	− 1·3
6903	Y	Apr. 4	65	592·640	19·185	+ 13·4	4	− 5·0
6907	H	Apr. 7	80	595·637	22·182	+ 12·3	2	+ 8·3
6914	H	Apr. 8	80	596·657	23·202	− 0·1	4	+ 1·5
6916	H-P′	Apr. 12	66	600 734	27·279	− 27·5	5	− 1·1
6925	H	Apr. 14	65	602·641	29·186	− 35·8	5	+ 1·2
6931	Y	Apr. 15	45	603·644	30·189	− 38·7	4	+ 3·3
6933	P	Apr. 17	70	605 733	32·278	− 56·8	4	− 7·4
6936	P′	Apr. 19	79	607·802	34·347	− 43·7	6	+ 8·3
6940	Y	Apr. 20	60	608·667	35·212	− 52·0	7	− 0·8
6949	C-P′	Apr. 21	72	609·725	36·270	− 46·3	3	+ 2·9
6957	Y	Apr. 28	60	616·622	4·867	− 9·1	5	− 2·6
6968	H	May 6	75	624·650	12·895	+ 34·1	5	+ 4·3
6973	Y	May 9	65	627·651	15·896	+ 28·9	7	+ 0·5
6980	P′	May 10	85	628·682	16·927	+ 35·9	4	+ 9·8
6984	H	May 11	75	629·719	17·964	+ 24·2	2	+ 1·2

TABLE III.—OTTAWA OBSERVATIONS—(*Continued*)

Plate	Obs.	Date	Exp.	Julian Day	Phase	Velocity	Wt.	O-C
		1915						
6987	H	May 13	72	2,420,631·638	19·883	+ 12·2	7	− 3·3
7004	C	May 19	48	637·747	25·992	− 8·2	2	+ 10·6
7007	Y	May 23	70	641·663	29·908	39·2	2	+ 1·8
7010	C	May 24	80	642·639	30·884	50·5	4	− 5·6
7016	P″	May 27	70	645·618	33·863	− 46·4	4	+ 5·5
7022	C	May 28	75	646·651	34·896	55·1	4	+ 3·5
7038	Y	June 1	70	650·587	00·532	− 42·9	5	− 4·5
7044	P″	June 2	86	651·616	01·561	43·1	1	− 12·1
7047	C	June 4	80	653·604	03·549	− 4·9	3	+ 12·1
7050	Y	June 6	70	655·656	05·601	− 0·4	5	+ 1·0

TABLE IIIA—OTTAWA OBSERVATIONS (SECONDARY)

Plate	Obs.	Date	Exp.	Julian Day	Phase	Velocity	No. Lines	O-C
6791	C	Feb. 17	70	2,420,546·764	11·609	− 71·8	1	+ 8·7
6853	Y	Mch. 9	55	566·710	31·555	+ 75·0	4	+ 9·0
6858	H	Mch. 11	60	568·710	33·555	+ 53·6	2	− 21·2
6894	H	Mch. 29	70	586·661	13·206	− 96·4	1	− 11·9
6898	Y	Mch. 30	60	587·698	14·243	− 80·0	3	+ 4·8
6936	P′	Apr. 19	79	607·802	34·347	+ 83·1	1	+ 7·3
6940	Y	Apr. 20	60	608·667	35·212	+ 65·8	1	− 8·7
6949	C-P′	Apr. 21	72	609·725	36·270	+ 68·9	1	− 1·6
6968	H	May 6	75	624·650	12·895	− 75·6	1	+ 8·4
6973	Y	May 9	65	627·651	15·896	− 89·8	3	− 8·0
6980	P′	May 10	85	628·682	16·927	− 92·2	3	− 14·7
6984	H	May 11	75	629·719	17·964	− 64·8	1	+ 6·2

The observations were grouped into 8 Normal Places which are given in Table IV. and from these, graphical elements of the orbit were obtained.

TABLE IV.—NORMAL PLACES

No.	Julian Day	Phase	Velocity	Weight	Residual
1	2,420,594·281	13·166	+ 28·5	2	− 1·2
2	612·611	16·982	+ 25·6	2·5	− 0·3
3	590·576	22·116	+ 5·5	3	+ 1·0
4	578·813	26·423	− 20·0	2·5	+ 1·2
5	604·194	30·739	− 47·4	3	− 3·0
6	609·249	34·558	− 50·0	4	+ 2·0
7	604·336	0·241	− 42·6	2	− 3·1
8	614·081	5·656	− 0·1	3	+ 1·4

The elements obtained graphically were :

$$P = 38{\cdot}3 \text{ days}$$
$$\gamma = -8{\cdot}95 \text{ km.}$$
$$K = 41 \text{ km.}$$
$$e = {\cdot}1$$
$$\omega = 240°$$
$$T = 2{,}420{,}575{\cdot}4 \text{ J.D.}$$

A least squares solution was carried through involving the elements γ, K, e, ω and T, giving the following corrections :

$$\delta\gamma = +{\cdot}06 \text{ km.}$$
$$\delta K = -{\cdot}01 \text{ km.}$$
$$\delta e = -{\cdot}028$$
$$\delta\omega = -16°{\cdot}65$$
$$\delta T = -1{\cdot}945 \text{ days.}$$

Hence the new values for the elements, to which has been appended the probable error of each :

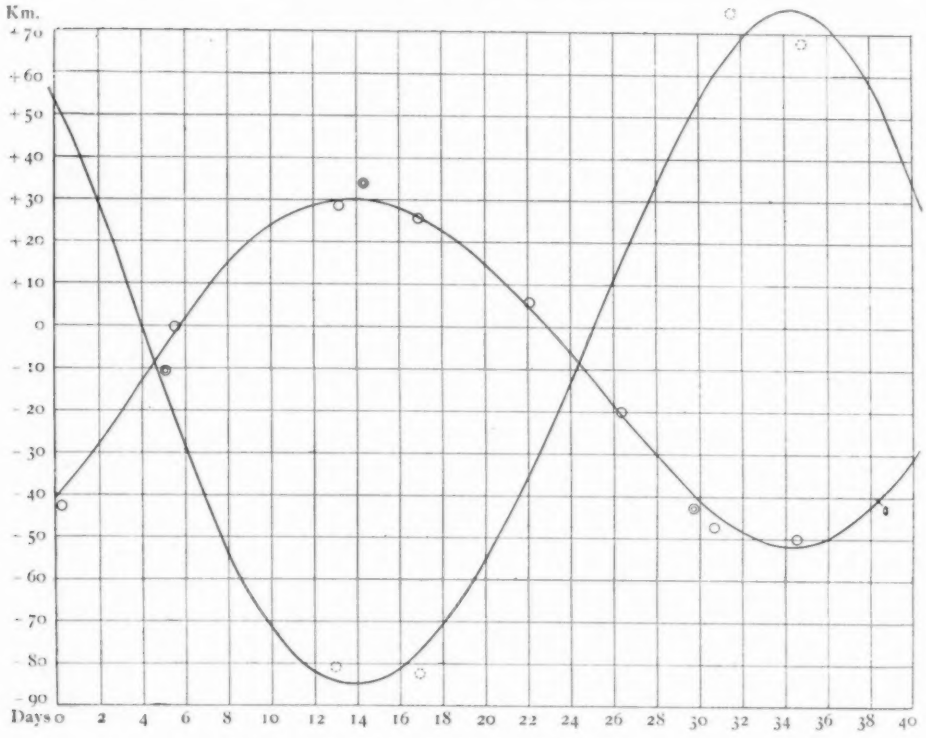
$$P = 38{\cdot}3 \text{ days}$$
$$\gamma = -8{\cdot}89 \text{ km.} \quad \pm {\cdot}55 \text{ km.}$$
$$K = 40{\cdot}99 \text{ km.} \quad \pm {\cdot}81 \text{ km.}$$
$$e = {\cdot}072 \quad \pm {\cdot}019$$
$$\omega = 223°{\cdot}35 \quad \pm 11°{\cdot}59$$
$$T = 2{,}420{,}573{\cdot}455 \text{ J.D.} \quad \pm 1{\cdot}216 \text{ days.}$$
$$a \sin i = 21{,}530{,}000.$$

The twelve plates of the secondary were grouped in normal places corresponding to those of the primary. These fell in four places corresponding with group 1, 2, 5 and 6 of the primary, four falling in group 1, three in group 2, one in group 5, and four in group 6.

The means are found below :—

Group	Phase	Velocity	Residual
1	12·988	− 80·9	+ 3·2
2	16·929	− 82·3	− 5·0
5	31·555	+ 75·0	+ 9·0
6	34·846	+ 67·8	− 7·2

These were plotted on the same sheet with the primary and the value of K' most suitable found by trial. This value was 80 km. ω in the secondary becomes 223°·35 + 180 or 43°·35.



VELOCITY CURVE OF BOSS 3323

Otherwise the values of the elements are the same as those of primary.

The probable error of an average plate in the primary is ± 3·5 and in the secondary ± 7·3. That of a normal place, (primary) ± 3·4.

The comparative values of the masses are given by

$M_1 : M_2 = K_2 : K_1 = 80 : 40\ 99$ or very close to 2 : 1.

In the figure the circles are Ottawa normal places, the double circles Adams' observations, and the broken circles secondary normals.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
August, 1915.

STÖRMER'S INVESTIGATIONS ON THE AURORA

By C. A. Chant

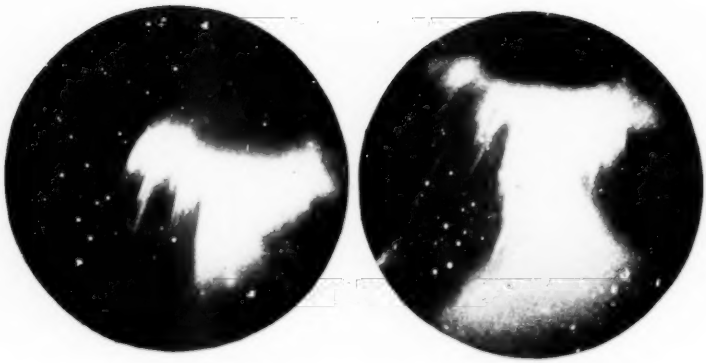
AMONG the researches on the aurora made during recent years, those by Professor Carl Störmer, of Christiania, Norway, must be given a high place. With his name might be coupled that of Professor Kr. Birkeland, also of Christiania, who has been very active in the same field, and who, I believe, was the author of the hypothesis that the aurora is produced by electrically charged corpuscles emanating from the sun and acted upon by the magnetic field of the earth.

In order to develop this theory Störmer applied mathematical analysis to it. Expressing the motion of a charged corpuscle in a magnetic field by means of differential equations, Störmer attempted to solve them in certain cases. The first results were obtained in 1904 and appeared to verify Birkeland's hypothesis. Since then, with the assistance of several computers (provided by the Fridtjof Nansen Fund) the work has been continued and the shapes of the paths of the corpuscles under various conditions have been calculated. Many of the curves are of peculiar beauty and strongly resemble auroral forms.

Störmer next undertook a study of the aurora by means of photography. He wished to secure pictures of various forms and also, by taking simultaneous photographs of the same aurora at stations a sufficient distance apart, he hoped to obtain pa rs of pictures which would exhibit apparent displacement of the aurora with respect to the stars in the background. These displacements would permit the height of the aurora above the earth and its distance away to be computed.

With this programme before him Störmer, accompanied by B. J. Birkeland, a meteorologist, in the spring of 1910 went to Bossekop, which is near the northerly limit of Norway and which

PLATE XXV.



At Store Korsnes At Bossekop

SIMULTANEOUS PHOTOGRAPHS OF AURORA

In the form of a luminous tranquil surface, taken at two stations 27·5 km. apart
March 11, 1913, 12h 53m.

(About 1½ times original size).

is famous for its auroral displays. Indeed, many expeditions have been made to this place for the study of the aurora.

Many excellent photographs of the aurora were obtained and also 44 pairs of plates from which parallax measurements could be made. About 130 heights were calculated from them, the lowest being 36 and the highest 366 kilometres. The most usual height, however, was between 100 and 140 km., or on the average 120 km. (75 miles).

This expedition was so successful that a second one was made three years later. In 1910 the two stations at which the simultaneous pictures were taken were 4·5 km. apart, but on this occasion one was at Bossekop while the other was at Store Korsnes, 27·5 km. due north. The cameras chiefly used had "kinostigmat" lenses, having aperture 1 inch and focal length 2 inches, and of course the most sensitive plates were employed. The two stations were connected by telephone, each observer having a transmitter and a receiver fixed to his chest, so that each could communicate with the other instantly and with ease. A very large number of plate-holders had been secured and by means of changing boxes these could be filled or emptied in the open air. In addition it was arranged that an image of a watch-face should be obtained on each plate, the hour and minute hands showing the time when the exposure was made and the arc described by the second hand showing the length of exposure.

As a consequence of the admirable preparations, in the interval from February 28 to April 1, inclusive, 636 pairs of photographs were taken, of which 447 were successful. The extensive material obtained has not yet all been worked up, but in a recent number of *Terrestrial Magnetism and Atmospheric Electricity* a preliminary account, based on one-sixth of the whole, was published, and as the information given is so definite and interesting I give a brief review of it here.

In Plate XXV. two pictures of the same aurora, obtained on the night of March 11-12, 1913, at $12^h\ 53^m$ are shown. At this time, Professor Störmer states, the sky in the south was covered with remarkable luminous, tranquil areas, mixed with

rays and dark openings. The whole remained unchanged for several minutes and was a very good object for the cameras. Four successful pairs were taken between $12^h\ 52^m\ 30^s$ and $13^h\ 1^m\ 14^s$, and they showed very little change during this time. In the photograph it will be noticed that the stellar images near the centre of the plate are very good, being round and sharp, but toward the edges they are somewhat distorted as we might expect from the lens used, which was designed for extreme rapidity.

In Figure 1 is a sketch made from the two photographs. The

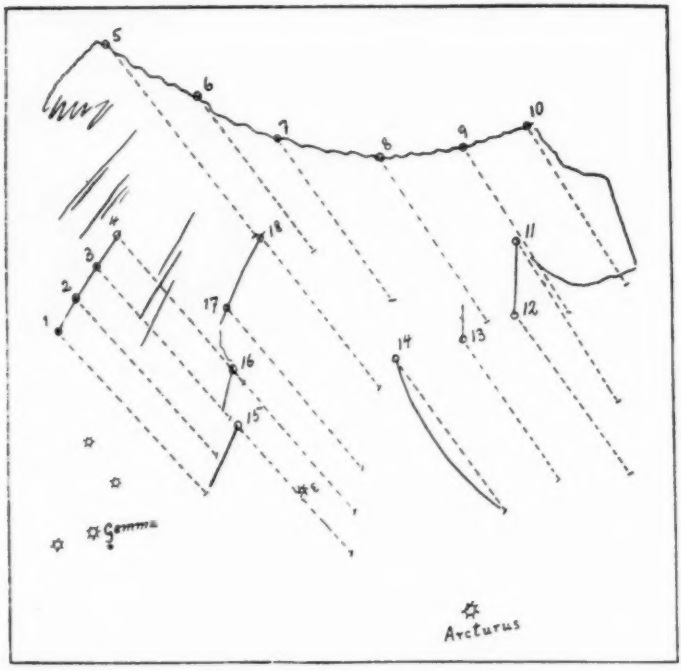


FIGURE 1.—SKETCH COMBINING THE TWO PHOTOGRAPHS SHOWN IN PLATE XXV.

The dotted lines show the apparent displacement or parallax.

dotted lines join similar points on the two pictures and their lengths show the parallactic displacements of the 18 chosen points. Calculations gave the heights of these points above the earth in kilometres, as follows :—

No. of Pt.	1	2	3	4	5	6	7	8	9
Height	96	103	109	118	132	118	118	114	117
No. of Pt.	10	11	12	13	14	15	16	17	18
Height	120	117	101	116	106	112	106	98	115

The aurora, as a whole, was about 80 km. south-east of Bossekop, and the points on the earth immediately below the various chosen points in the aurora are shown in Figure 2.

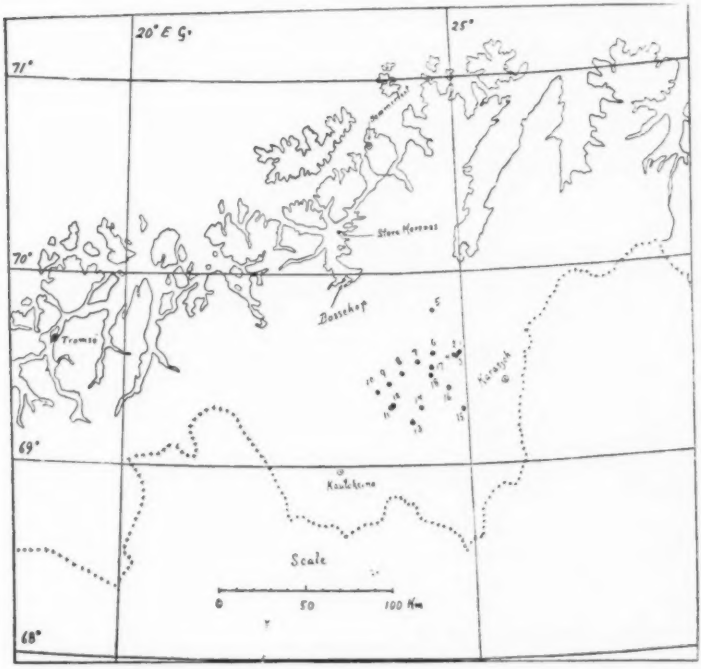


FIGURE 2.—MAP SHOWING BOSSEKOP AND STORE KORSNES AND THE PLACES AT WHICH THE AURORA WAS VERTICALLY OVERHEAD

As has been already remarked, Störmer has endeavored to develop that theory according to which the aurora consists of electrically charged corpuscles moving in the magnetic field of the earth. Now during the night of March 11-12 at about $12^h\ 30^m$ there suddenly appeared in the west a very intense auroral drapery which rapidly developed eastward, passed directly over Store Korsnes and continued northeastward. The color was greenish white and the intensity was so great that some good pictures were obtained with an exposure of only one second. On a cinematograph film usable pictures were obtained with an exposure of about 0·3 second. Since electrically charged particles in motion constitute an electric current they should

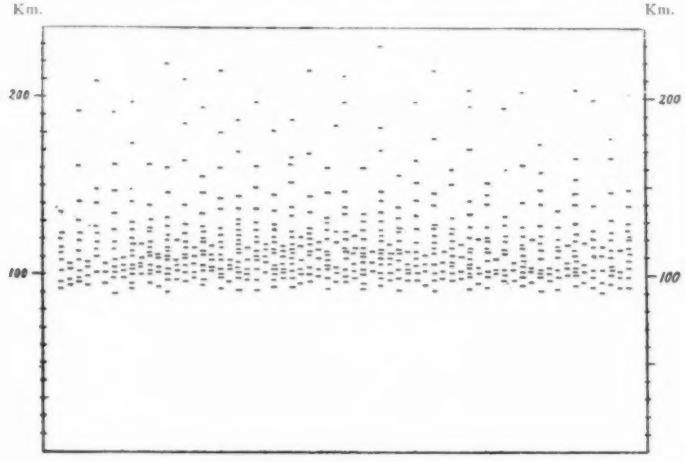


FIGURE 3.

DIAGRAM SHOWING CALCULATED HEIGHTS OF VARIOUS AURORÆ.
Observe that very few are less than 90 km. and the majority are about 100 km.

deflect a magnetic needle in the neighborhood. But 17 km. west from Bossekop, at Haldde, is a small magnetic observatory, established for the purpose of studying just such problems as these, and an application to the director secured the magnetic curves registered photographically during the night They

showed that the magnetic disturbance was decided at midnight and for some time afterwards. Now assuming that the electric corpuscles descend into the atmosphere from without, along the magnetic lines of force, thus forming auroral rays, which combine to form the drapery, Störmer showed that a magnetic action like that registered would be produced if positive electricity were coming down along the rays of the drapery. This evidence then strongly points to the conclusion that the aurora is caused by positively charged electric corpuscles.

In Figure 3 all the heights measured so far are given. It will be seen that the auroræ were, as a rule, above 100 km. high. As there was a sunspot minimum in 1913 it might be expected that the corpuscles coming from the sun would have little penetrating power and would be stopped high up in the atmosphere producing the displays there, which is just what we find.

MEETINGS OF THE SOCIETY

At Toronto

October 5, 1915.— The Regular Meeting of the Society was held in the society's Rooms at 198 College Street. Dr. A. D. Watson was in the chair.

Kindly reference was made by the Chairman to the passing, since our last meeting, of Sir Sandford Fleming and W. H. S. Monck, Esq., late Fellows of our Society.

The Assistant Librarian reported on the number of periodicals received during the summer and the additions made to the library by purchase and by donation.

Progress Report by the Observatory Committee was presented to the Society by Dr. Watson.

An interesting discussion took place following reports of observations during the summer months by different members of the Society, and centred chiefly about the auroræ and kindred phenomena ; which are approaching their maximum frequency for the present eleven-year period.

October 19,— Regular meeting of the Society held in the Rooms at 198 College Street; Mr. A. F. Hunter in the chair.

The following were elected members of the Society, having been proposed for membership at the last regular meeting :—

Rev. W. T. B. Crombie, M.A., B.D., Athelstan, Quebec.

Mr. G. S. Dunbar, Pittsburgh.

Mr. G. Gunner, Toronto.

Mr. Jas. Weir, B.Sc., Montreal.

Mr. B. S. Wimbush, Garden Plain, Alberta.

Mr. Collins referred to the Predictions in the HANDBOOK for the next two weeks. Under "Notes and Queries" some interesting questions were raised as to the motions of the heavenly bodies and if there was any explanation why most of the bodies were direct in their rotatory motions.

The paper for the evening was then given by R. F. Stupart, F.R.S.C., Director of the Meteorological Service, on "Weather Forecasts," and the members who were not present missed a great treat. After giving a historical review of the growth of local weather predictions from early times, reference was made to the general movements of the air and the usefulness of the barometer in conjunction with winds in recording these motions. Conditions leading to precipitation were then explained (*a*) Cyclonic areas; (*b*) Warm moist air forced up over cold air; (*c*) Trough of warm stagnant air into which cold air is forced; and (*d*) Topography, as shown in British Columbia with prevailing west winds. He also stated that in predictions the tendency to maintain persistency of type must be reckoned with.

Characteristics of the climate of the different sections of Canada were then given by the lecturer.

Fine weather is usually associated with high barometer, and bad weather with low barometer, but there are many exceptions. By means of lantern slides of synoptic charts the difficulty to be met with in making predictions of weather was shown by some concrete examples, and also others showing typical maps of low and high pressure areas, and their general movements, and the variations in the weather in different parts of these areas.

November 2,— A regular meeting of the Society was held in the Society's Rooms at 198 College Street, this evening; Mr. A. F. Hunter in the chair.

The Assistant Librarian reported on the number of publications received during October.

Mr. J. R. Collins referred briefly to the predictions for the next two weeks as recorded in the HANDBOOK."

Under "Reports of Observations" many members reported

auroræ, and reference was made to Professor Pickering finding the atmosphere at Jamaica as well suited as any for astronomical observations.

The paper for the evening was given by Mr. J. A. Paterson on "Robert Ball and His Life-Work." In his usual lucid and pleasing manner he brought the great astronomer and his work vividly before the members present, and doubtless inspired many with the thought that they would know more of Robert Ball and Astronomy.

W. E. W. JACKSON, *Rec.-Sec.*

AT OTTAWA

April 9, 1915.— The Seventh Meeting of the Term was held this afternoon at 3 o'clock, in the Geodetic Survey Building, Mr. F. A. McDiarmid presiding.

Mr. J. E. Ratz gave a paper on "The Influence of Laplacian Points." Mr. Ratz introduced the subject by explaining the difference between astronomic and geodetic observations, illustrating the fallacy of using isolated astronomic observations as a control for a careful primary triangulation, by a comparison of the positions of a few points as determined, firstly, on the Canadian observations and, secondly, on the North American.

To make possible the incorporation of astronomic values in the adjustment of triangulation, use is made of Laplace's equations:

Astron. Azimuth − Geodetic Azimuth = (Geodetic Long. − Astron. Long.) × sine Lat.

The astronomic values can be determined in general more accurately than geodetic values, so that the corrections necessary to satisfy the above equation are made to apply to the geodetic values only. Mr. Ratz based his remarks upon the results obtained from the introduction of two Laplace points, giving rise to four Laplace equations, in the Ontario primary triangulation. These equations indicated that the network of triangles had a tendency to bend to the southwest. The maximum correction needed to satisfy all of the Laplace equations was 23′. The

maximum correction needed to satisfy the base conditions was 8′ — only one-third of that due to twist. Hence, the necessity of controlling the twist of a triangulation becomes of extreme importance, not even second to length controls. As yet no method has been obtained which allows one to arrive at the amount of twist in a triangulation ; but if we assume the simple ratio as indicated by the corrections, to be a criterion for the number of Laplace equations to that of length controls, we arrive at the conclusion that from two to three times as many Laplace equations are required as bases.

Mr. J. H. Moorehouse then gave a paper on "Base-Line Measurements." Mr. Moorehouse first described the "Invar" tapes used. Invar is an alloy of nickel and iron. The co-efficient of expansion due to increase of temperature is given as 1/25th that of steel ; but for the tapes used in the Canadian Geodetic Survey the co-efficients were found to be 0·00000137 and 0·00000074 for 1°C., as compared with 0·000012 for steel. The tapes used are 0·025 inch by 0·02 inch in section. They change length slowly, the curve with time being a parabola. From October, 1908, to November, 1909, there was a shortening of 2·423 mm. in a 50 metre tape.

In selecting a base-line it is necessary to take precautions, such as securing a level region having all parts uniformly exposed ; along a railway line a good stretch may be found usually. For the measurements, weight tension, steady atmosphere and even temperature are necessary.

Some discussion of these papers followed. The thanks of the meeting were tendered the lecturers, and the meeting adjourned.

April 23,—The Eighth Meeting of the Spring Term was held this evening, at 8 o'clock, in the Carnegie Public Library, Mr. F. A. McDiarmid presiding.

Mr. T. H. Parker, M.A., gave a lecture on "The Spring Constellations." Mr. Parker showed the positions of the more important constellations seen in the spring months, outlining

their configurations and describing the interesting bodies in them. A series of slides illustrated his remarks. In discussing each constellation he showed how the name was derived, giving an account of the interesting myths connected with them.

At the conclusion of the lecture a hearty vote of thanks was tendered to Mr. Parker; after which the meeting adjourned.

April 30.— The Society held its Ninth Meeting of the Term in the Geodetic Survey Building to-day, at 3 o'clock, President F. A. McDiarmid in the chair.

Dr. R. K. Young gave a paper on "The Motions of the Nearer Stars."

Dr. Young outlined briefly the method by which the mean distance of a group of stars may be obtained from their proper motions and radial velocities. He applied the method to 167 stars, for which determinations of distance have been made by direct measurement. The computed mean distance was then compared with the observed values. The results seemed to show that for the stars utilised the observed mean distance was too great:

Computed parallax = 0″·106; observed parallax = 0″·072.

A second solution was then made, dropping the stars whose parallax was greater than 2″:

Computed parallax = 0″·088; observed parallax = 0″·065.

A third solution, dropping stars with parallax greater than 1″.

Computed parallax = 0″·073; observed parallax = 0″·062.

The direction of the solar motion from the 167 stars was found to be $\alpha = 270°$; $\delta = +14°$, as compared with the usually accepted value, 270°. + 30°.

Some discussion of various points in the lecture followed. A hearty vote of thanks was tendered the lecturer, and the meeting adjourned.

June 21.—The tenth and last meeting of the Term — the

"Open Air Meeting"—was held this evening, at the Observatory, being postponed from June 19 on account of cloudy weather. The evening promised to be clear, but clouds came up later and after the numerous visitors had seen the various instruments in the building they assembled in the lecture-room of the Geodetic Survey Building, where Mr. W. E. Harper, M.A., gave an interesting "lantern talk." Mr. Harper made a selection of the most interesting slides on the Sun, Comets, Nebulæ, Star Clusters, Moon, Planets, etc., and the visitors were well pleased with the evening's entertainment. It would seem advisable—on account of the large number attending this meeting—that an "Open Air Meeting" become an annual affair of the Society.

R. E. DeLury, *Sec.*

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

October, 1915

Temperature.— The mean temperature of the month was above average in all parts of the Dominion, exclusive of the British Columbia coast line, and the extreme southwestern portion of Nova Scotia ; also perhaps in far northern Manitoba and Patricia. The largest positive departures from normal were from 3° to 4° in eastern Ontario and in Quebec, and about 6° in the southern parts of Alberta and Saskatchewan.

Precipitation.— The rainfall was less than average throughout the Western Provinces and in the more southern and eastern portion of Ontario ; also in the central portions of the Maritime Provinces. Over British Columbia generally there was a marked excess of the average, except in the normally dry belts. In Northern Ontario and over the larger part of Quebec and in Southern Nova Scotia the rainfall was slightly in excess of the average.

Temperature for October, 1915

Station	October		Station	October	
	Highest	Lowest		Highest	Lowest
Yukon			Huntsville	72	23
Dawson	56	- 4	Kenora		
British Columbia			Kinmount	68	18
Atlin			Kingston	69	28
Agassiz	68	33	London	76	24
Barkerville	53	20	Lucknow	74	20
Kamloops	70	30	Markdale	75	28
New Westminster	66	38	North Gower	70	18
Prince Rupert	58	34	Oshawa	70	28
Vancouver	62	38	Ottawa	72	26
Victoria	63	43	Paris	72	28
Western Provinces			Parry Sound	72	26
Battleford	72	21	Peterboro'	71	24
Calgary	76	26	Port Arthur	62	28
Edmonton	72	16	Port Burwell	70	29
Medicine Hat	78	28	Port Dover	72	27
Minnedosa	68	17	Port Stanley	69	26
Moose Jaw	77	22	Queensborough	68	24
Oakbank	67	23	Ronville	70	27
Portage la Prairie	74	23	Southampton	77	28
Prince Albert	66	20	Sundridge		
Qu'Appelle	70	20	Stonecliffe	73	23
Regina	72	18	Stony Creek	77	29
Saskatoon	71	21	Toronto	74	30
Souris	67	18	Uxbridge	72	19
Swift Current	76	22	Wallaceburg	76	25
Winnipeg	70	24	Welland	78	27
Ontario			White River	66	12
Agincourt	74	25	*Quebec*		
Aurora	71	23	Brome	74	21
Bancroft	68	18	Father Point	66	26
Barrie	73	27	Montreal	70	31
Beatrice	72	24	Quebec	66	28
Berlin	73	27	Sherbrooke	72	24
Bloomfield	69	28			
Brantford			*Maritime Provinces*		
Chapleau	65	21	Charlottetown	72	30
Chatham	79	27	Chatham	72	28
Clinton	75	23	Dalhousie	63	29
Collingwood	76	25	Fredericton	75	26
Cottam	79	25	Halifax	72	30
Georgetown	74	26	Moncton	73	26
Goderich	74	30	St. John	66	32
Gravenhurst	71	23	St. Stephen	71	22
Grimsby			Sussex	69	24
Guelph	74	26	Syndey	72	30
Haliburton	70	20	Yarmouth	60	32

MAGNETIC OBSERVATIONS

October. 1915

During the first two weeks of October the magnetic forces, as shown by the photographic record obtained at Agincourt, were normal, but during the remainder of the month great activity was displayed. On the 14th at $8^h\ 47^m$, the largest disturbance of the month began with a sudden increase of $2'{\cdot}5$ in West Declination and 19γ in Horizontal Force, and 5γ in Vertical Force. These movements were followed by large but slowly occurring changes in Declination and rapid pulsations in Horizontal at first, gradually becoming larger in magnitude and slower in occurrence. In Vertical, movements were small up to 21^h and then occurred a large diminution of Force until $15^d\ 4^h$, followed by a gradual increase to a high maximum at $15^d\ 16^h\ 34^m$, and gradual return to normal again early in the morning of the 16th. Pronounced peaks were recorded in both Horizontal and Vertical, with minimum force at $15^d\ 0^h\ 28^m$, and $15^d\ 3^h\ 56^m$, and maximum force at $15^d\ 16^h\ 35^m$.

On the 23rd another pronounced disturbance was recorded with a sudden commencement at $7^h\ 50^m$. In Declination, a decrease of west declination of $1'$ was followed by rapid increase of $6'$ and then small rapid changes. In Horizontal, an increase 14γ was followed by a decrease of 112γ with rapid pulsations of force until noon. In Vertical, a small increase of 5γ was followed by small slow changes of Force until noon. At $18^h\ 34^m$ a second sudden movement was recorded. In Declination, the west declination increased quickly $23'$ and was followed by large rapid vibrations which gradually subsided, the trace becoming normal again during the afternoon of the 26th. The Horizontal Curve indicates a sudden decrease of $9{\cdot}4\gamma$ followed by large rapid oscillations of force which gradually become less pronounced as in the Declination Curve. The Vertical Curve shows a sudden increase of 5γ and then a fall of 48γ and then as in the others it was followed by large rapid changes until $24^d\ 2^h$, and became normal again in the afternoon of the 26th.

Smaller disturbances were recorded on the 17th, from the 19th to the 22nd, on the 27th, 30th and 31st.

Auroræ of the I. and II. Class were recorded quite generally over Canada from the 14th to the 23rd.

A large sunspot group was centred on the sun's surface on the 13th and gradually diminished in size as it neared the limb of the sun. Two large groups, one north and one south of the equator, were central on the 18th and 19th, and another small group north of the equator was central on the 23rd.

October, 1915		D. West	H	V	I
		° ′			° ′
	Mean of Month	6 30·2	0·16005	0·58614	74 44·5
	Maximum	6 57·6	0·16108	0·58870	
	Date of Maximum	15	15	15	
	Minimum	5 58·7	0·15801	0·58430	
	Date of Minimum	15	15	23	
	Monthly Range	0 58·9	0·00307		
Mean Daily Amplitude	From hourly readings	0 8·1	0·00041	0·00024	
	From Means of Extremes	0 21·5	0·00086	0·00063	

H and V are expressed in C. G. S. Units.

I is the Mean of all Dip observations made during the month with the Earth Inductor, without regard to the time of day at which they are made. Two observations are usually made each week, one in the morning near the time of maximum Dip and the other in the afternoon near the time of minimum Dip.

Earthquake Records by the Milne Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. A.C. = Air Currents.

Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1915		P. T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
			h m	h m	h m	h m	mm.	h m	
1518	Oct.	2		23 57·7	23 58·4	24 2·0	0·2	0 4·3	
1519	"	3	1 59·7	2 6·1	2 6·7	2 17·5	0·3	0 17·8	Washington State.
			S 2 4·4						
1520	"	3	6 59·6	7 7·2	7 10·5)	10 40·7	over 27·0	3 41·1	3·164 km. L. W. continued for a long time. Nevada.
			S 7 4·5		7 11·6		16·0		
					7 12·3)		12·0		
1521	"	5		14 14·5		14 53·5	0·1	0 39·0	
				14 50·4					
1522	"	10	6 44·9	6 54·1)	7 3·5	7 17·1	0·2	0 32·2	
				6 59·9)					
1523	"	10		10 20·0		10 32·0	0·05	0 12·0	
1524	"	11	S 2 54·6?	3 5·7	3 8·0	3 18·0	0·2	0 23·4	
1525	"	11	19 40·1	19 50·5	19 53·8	20 39·8	1·6	0 59·7	2·109 km.
			S 19 43·7						

12th earthquake missed, clock stopped.

Period of boom = 18 seconds. Pillar duration 1 mm. = 0″·59.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1915	P.T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
1517	Oct. 2	23 44·5	23 44·9	23 45·5	23 52·0	0·6		220 km. Washington [State.
1518	" 3	1 52·5	1 52·9	1 53·8	2 00·4	2·2		220 km. Washington [State.
1519	" 3	6 54·9	S or L 6 57·2	6 57·4) 7 0·8)	10 35·4	17·0 38·0	3 40·5	1300 km. Nevada.
1520	" 5	14 08·9 S 14 11·9	S or L	14 14·6	14 43·9	0·2	0 35·0	1740 km. California.
1521	" 10	6 32·8	6 35·3	6 40·1	6 49·8	0·2	0 17·0	143) m.
1522	" 10	10 32·3	10 33·1	10 34·3	10 38·1	0·1	0 5·8	440 km.
1523	" 11		3 14·2) 3 17·3)	3 22·3	3 39·2	0·05	0 25·0	Boom appears un- [steady before 3h. [14m·2 impossible to [measure.
1524	" 11	19 58·5 S 20 03·0	20 08·3	Cut off	20 39·0		0 40·5	
1525	" 12	1 34·1	1 36·9	1 39·4	1 44·3	0·6	0 10·2	1650 km.
1526	" 12	22 06·9	P and L	22 09·0	22 11·9	0·1	0 5·0	
1527	" 28	16 17·1	16 17·1	16 18·1	16 20·1	0·1	0 3·0	
1528	" 31	10 25·9	10 25·9	10 26·4	10 28·8	0·1	0 2·9	

Boom Period = 18 seconds. 1 mm. = 0″·54

Following are times of phases registered on the Wiechert Vertical Seismograph at Victoria for October 3rd. During the large Nevada earthquake.

Oct.	3	6 55·4 S 6 57·2	6 58·5	6 59·7		μ 100	Movements well defined.

J. Y.

ASTRONOMICAL NOTES

RECENT WORK ON DOUBLE STARS.—The announcement that the great double-star survey undertaken by Professor Aitken has been brought to a successful conclusion will make the year 1915 the starting-point of a new period in this branch of astronomy. Up to the end of the nineteenth century little had been done for the detection of faint close pairs, but now that this has been undertaken, and so completely, it is to be hoped that the possessors of large refractors will make it a duty to re-measure the thousands of different faint stars found within the last fifteen years. The great problem now open to double-star astronomy is to find what information is to be derived from these stars. If amongst this class of star were found a number of rapid systems, it would go far to prove that the actual range of brightness amongst stars is so great that their apparent magnitudes give no clue to their probable parallaxes. The separation limit of 5″ as adopted by some observers for the 9th magnitude could perhaps then, with a possibility of equal interest, stand for all magnitudes.

The first list of stellar parallaxes recently published by the Royal Observatory, Greenwich, contains forty stars: there are nine stars brighter than $7^{m}\cdot0$ and eight fainter than $8^{m}\cdot9$, yet both classes include three parallaxes of more than $0''\cdot05$, and the largest parallax given belongs to a star of $9\cdot1$ visual or $9\cdot8$ photographic magnitude. These "exceptions" make one very hopeful with regard to the number of interesting systems which may be revealed be re-measuring the more recently discovered close pairs.

A very important contribution to this year's double-star astronomy is Vol. XII. of the *Publications of the Lick Observatory*, and one is filled with admiration at the activity of Professor R. G. Aitken, who has discovered 3000 new double stars, has found time to measure all the most important double stars known, and to compile, with such thoroughness, the volume under discussion. In addition he has made very numerous observations of comets, of the satellites of Mars, Jupiter, Saturn, and Uranus, and has computed several cometary orbits.

Comparing his observations of 56 *binaries* with fairly reliable orbits, Professor Aitken obtains as the mean error of his observations 2°·36 in position angle and 0″·059 in distance. Employing 48 *fixed* pairs showing no relative motion I have found the mean error of Aitken's measures to be 1°·6 and 0″·06. The fixed pairs used had a mean separation of about 2″. The agreement of the two opposite methods is as good as could be expected. — R. JONCKHEERE, in *The Observatory*, No. 493.

VARIATIONS IN THE EARTH'S RATE OF ROTATION. — Summary. — On the assumption that the error in heliocentric longitude of a planet is proportional to its mean motion, three separate determinations of the errors of position of the earth or sun have been made. These results showed a satisfactory agreement, and the mean resultant curve closely resembled the curve of the moon's error of longitude. To obtain further confirmation of the results and to justify the original assumption, the errors of Venus have been examined, and these agree both in the scale and nature of the variations with the adopted hypothesis of slight variations in the rate of rotation of the earth. A similar analysis of the errors of Mercury would not be justified by the nature and extent of the material available. — H. GLAUERT, in *Monthly Notices*, R. A. S., Vol. LXXV., No. 9.

ON THE NUMBER OF NAKED-EYE VARIABLE STARS. — As a result of his search for variable stars in globular clusters, Bailey found that about 2·5 per cent of all the stars examined show distinct light-variation; this percentage was compared with the

number of variables among the naked-eye stars, which he placed at 1 per cent. Since that study was made the number of known variable stars has considerably increased. In order to get an idea of the percentage of naked-eye stars now known to be variable, and to see how they are distributed in the different variable star classes for each interval of magnitude, the data in Table VI. were collected.

TABLE VI.

Magnitude	Long Period	Short Period	Eclipsing	Miscellaneous	Total Variables	Total Stars	Percentage Variable
< 1·0 ..	0	0	0	5*	5	12	17 per cent*
1·0 to 1·9 ..	0	0	1	1	2	28	7
2·0 to 2·9 ..	1	1	5	1	8	105	8
3·0 to 3·9 ..	3	6	4	7	20	275	7
4·0 to 4·9 ..	5	4	4	9	22	750	3
5·0 to 6·0 ..	18	7	4	20	49	2160	2
Total ..	27	18	18	43	106	3330	3

*Three of the five variables of this magnitude are Novæ, and, as they are now from the ninth to the twelfth magnitude in brightness, they are not included in the percentage.

The second, third, fourth and fifth columns give the number of variables belonging to the different classes named, whose brightness at maximum light corresponds to the magnitude tabulated in the first column. In the class "Miscellaneous" are included variables with unknown or irregular periods and the Novæ. Column six contains the total number of variables, and seven the total number of all stars, while the final column gives the percentage of variables in each magnitude division. It is seen that 3 per cent of all stars visible to the naked eye are known to vary in light.

In collecting this material the many bright stars recently suspected of small variation by Lau and Guthnick have not been considered, although many of them will probably be admitted soon to the lists of known variables. Had they been included the total percentage would be increased from three to more than five. —HARLOW SHAPLEY, *Contributions from the Mount Wilson Solar Observatory*, No. 99.

MEASURING THE HEAT FROM THE STARS.— Glass is as impervious as steel to the longer waves of the infra-red, and rock-salt lenses and prisms must be used to transmit them. In its perfected form, as employed by Abbot, the bolometer has become an automatic recording instrument of perfect reliability, serviceable in a score of ways to the student of astrophysics. Already, in conjunction with an improved pyrheliometer, it has demonstrated the sun to be a variable star, and measured its fluctuations in heat radiation.

The detection and measurement of the almost infinitesimal heat which reaches us from the stars is a task of very recent achievement, carried to a high degree of success by Coblentz at Mount Hamilton in 1914. Nichols, using a radiometer sensitive to the light of a candle five miles away, (assuming no atmospheric absorption) had measured the heat radiation of Arcturus and Vega at the Yerkes Observatory in 1900. Pfund improved materially on his results, and Coblentz has now accomplished the remarkable task of measuring the heat from stars beyond the limit of naked-eye visibility.

The apparatus employed for this work is an improved form of thermopile, an instrument which dates from 1830, when Nobili and Melloni constructed from strips of antimony and bismuth a heat-measuring device ten times as sensitive as the best thermometer of the day. The thermopile of Coblentz, consisting of a very small bismuth-platinum junction supported in a vacuum chamber at the focus of the three-foot mirror of the Crossley reflector, would give a galvanometer deflection of 1 mm. when exposed to the radiaton of a candle 53 miles away, if there were no atmospheric absorption. Dr. Coblentz believes that the sensitiveness of the thermopile-galvanometer combination can be increased sufficiently to detect the radiation from a candle 500 miles away, if employed in conjunction with a seven-foot mirror. Under such conditions work of great value could be done on the spectral energy curves of stars.—From G. E. HALE'S address on "The Work of a Modern Observatory," *Publications Astronomical Society of the Pacific*, No. 160. J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amatuers. The Editor will try to Secure Answers to Queries.

MORE OBSERVATIONS OF THE AURORA

Under date October 24, Mr. H. Westoby, of Guelph, sends the following note :—

At 9.30 last evening I was on my way home and noticed a crowd of people looking at the northern sky. Following their example, I saw what appeared to be a dark greenish cloud which tapered off into great streamers of white. It travelled so fast to the west that I was compelled to run up the street westward so as to follow it. Then the whole sky broke into a brilliant display, blue-green in color.

It was easily the most fascinating sight I have ever beheld in the skies and I only regretted that it moved so very rapidly and changed in formation so swiftly. The long streamers were half-way to the zenith. I watched afterwards until 11 p.m., but although there were many whitish streamers, usually single, I watched in vain for a re-appearance of the beautiful blue-green sight which I had witnessed earlier in the evening.

I do not know whether the full moon affected the color at all, but if it did not I should like to have put out its rays while that lovely aurora was passing as doubtless its beauty would have been greatly enhanced.

JEREMIAH HORROX

The present writer was much pleased to see the wide interest aroused by the paper on "Horrox" in the July-August JOURNAL, written by Dr. A. D. Watson. It was reprinted in

the *English Mechanic*, and Mr. H. P. Hollis, its astronomical editor, especially commended the illustrations. In the same magazine for September 10 is a letter written by Edward J. Jones, of Liverpool, from which the following extracts are taken:—

"Mr. Watson says that the slab to the memory of Jeremiah Horrox in Westminster Abbey supplements the one in the church at Toxteth. There are now a great many churches in Toxteth, and as some admirers of Horrox might like to visit the spot, I would point out that the church referred to is that of St. Michaels-in-the-Hamlet. . . . . .

Sir James Picton, in his "Memorials of Liverpool," states that the body of Horrox is probably interred within the precincts of the ancient chapel of Toxteth (adjoining the Dingle Car terminus) but no memorial is there erected to his memory.

The house in which Horrox lived as a child and died is now covered by the "Cheshire Lines" Otterpool Station. The exact spot I do not know. It is in the middle of a nicely wooded and pretty estate, formerly the property of Sir Thomas Moss, but now in the possession of the railway company. The present tenant is Mr. Cross, a well-known Liverpool curio dealer.

There are still several old places on the estate in the neighborhood which seem to have been contemporary with Horrox, and it is just possible that the secretary of the railway company, Mr. Glegge Thomas, may have some record locating the spot where the Lower Lodge, Horrox's house, stood, and I have no doubt he would be pleased to give any information to those interested in perpetuating the memory of one to whom we owe so much. . . . . .

The danger of Horrox's memorial being overlooked in Westminster Abbey among so many celebrities cannot apply here in Liverpool, as there is a most suitable spot facing the south entrance to Sefton Park upon which a really imposing monument could be erected, close by an old house dated 1666 and only a few minutes' walk from Horrox's birthplace.

C. A. C.

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